Neutrino Deep Inelastic Scattering with the MINERvA Experiment

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XX International Workshop on Deep-Inelastic Scattering and Related Subjects
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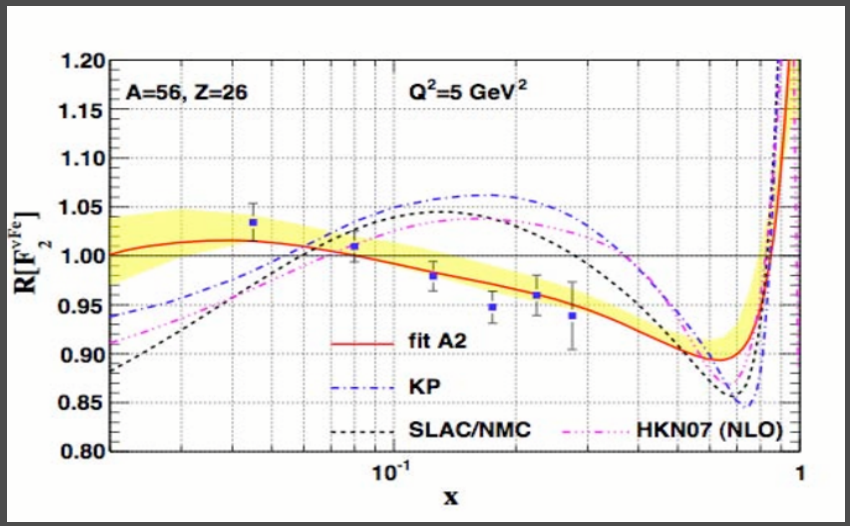
Outline:

- Motivation for studying neutrino DIS and MINERvA's DIS physics goals
- Description of the neutrino beamline and techniques for measuring neutrino flux
- Description of the MINERvA detector
- Performance of MINERvA reconstruction
- Description of the MINERvA test beam experiment
- Summary of charged current inclusive analysis and prospects for a DIS analysis

Neutrino DIS: Why Study it?

- Neutrino deep inelastic scattering very important for determining pdfs
- Neutrinos and anti-neutrinos are sensitive to different quark flavors. Strange quarks are accessible through charm production
- Multiplicity studies to examine hadron formation length
- Cannot use neutrino scattering data in global pdf fits until we understand the nuclear effects

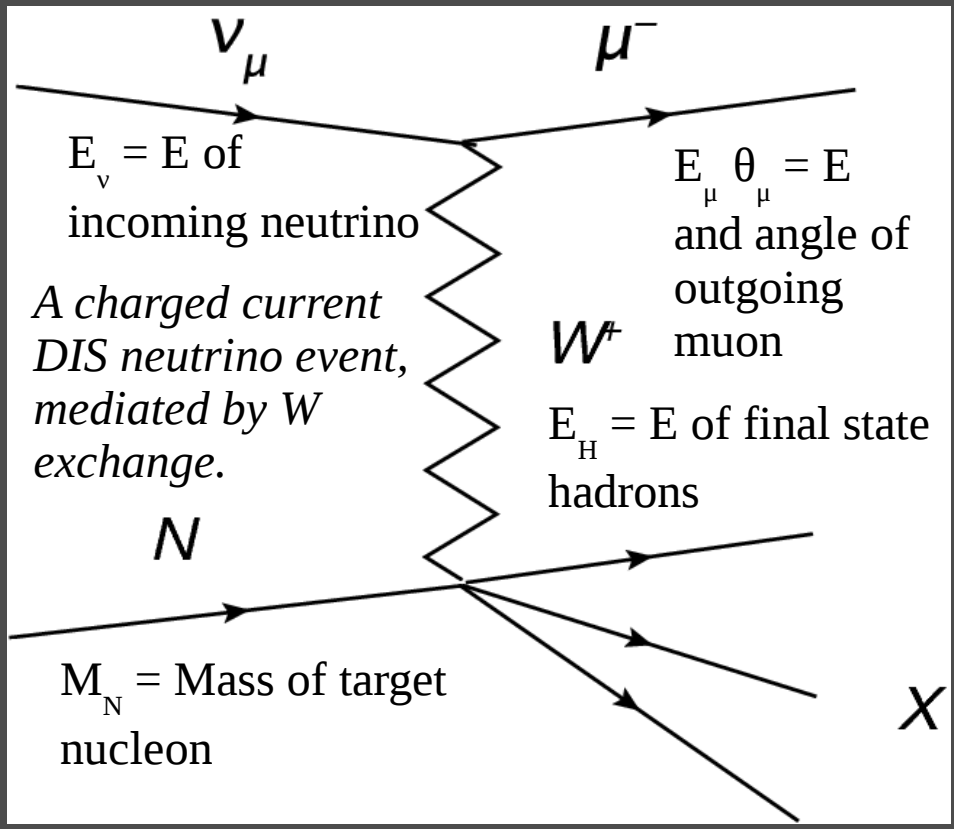
One experiment with one target! More data is needed!



CTEQ analysis of nu-Fe scattering
ArXiv: 1012.0286 [hep-ph]

Charged Current DIS Events

- Charged current events primary signal for neutrino experiments
- Final state is a charge muon of the same flavor as the incoming neutrino, plus various hadrons (p, n, π, hadron shower)
- Measure E_μ θ_μ and E_H
- CC-DIS is a *kinematic* cut on this signature of $Q^2 > 1$ GeV^2 and $W > 2$ GeV



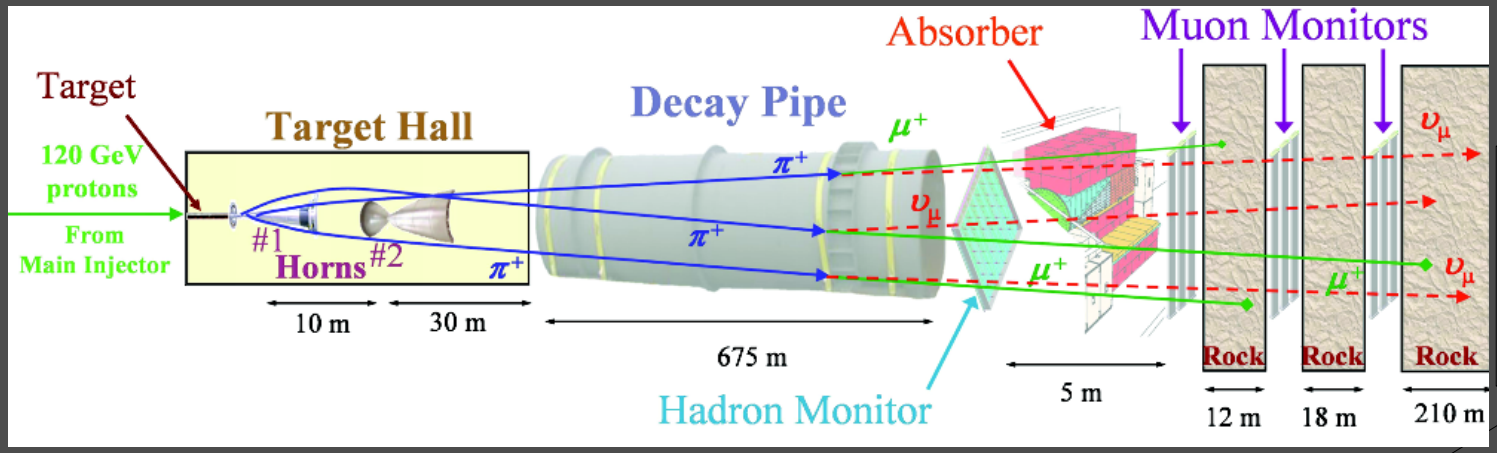
$$Q^2 = 4E_\mu E_\nu sin^2\left(\frac{\theta_\mu}{2}\right)$$

$$W^2 = M_N^2 + 2M_N E_H - Q^2$$

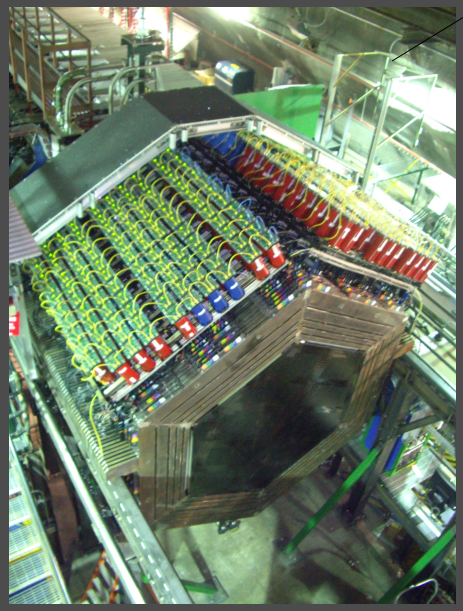
MINERvA's DIS Goals

- Select DIS events in tracker
- Reconstruct muon by leveraging MINOS. Working on a better understanding of high energy hadron showers
- Separate out DIS events, measure $d\sigma/dxdQ^2$ on various nuclear targets
- Calculate ratios between plastic / Fe, Pb, graphite, He and H_2O
- Simultaneously increase our knowledge of neutrino flux. Use it to calculate F_is in DIS and transition region

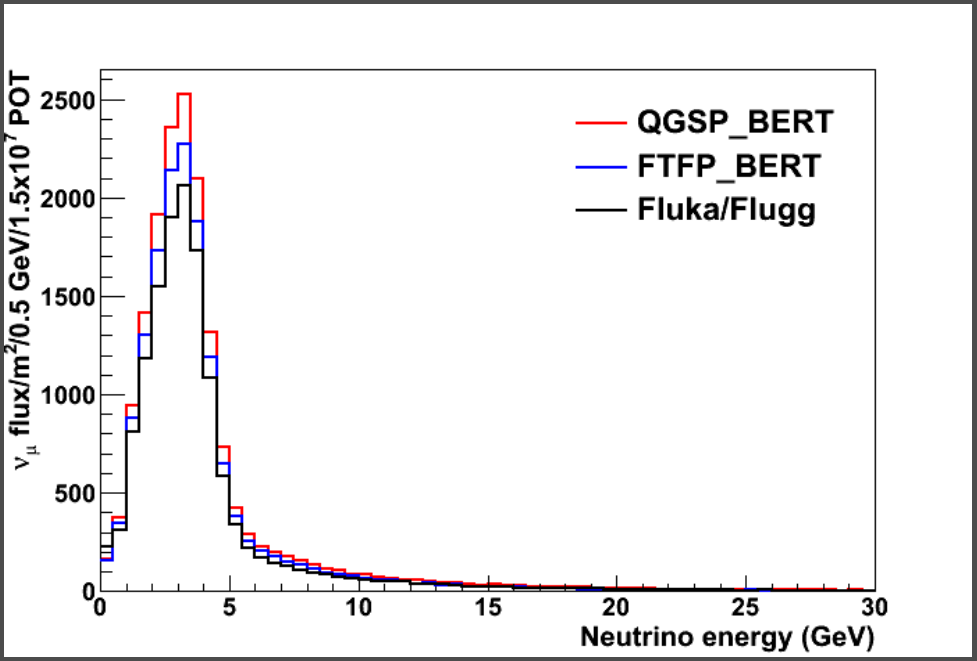
The NuMI Beamline



- MINERvA sits in the NuMI beamline at Fermilab in Batavia, IL
- 120 GeV protons collide with graphite target (~2.5 interaction lengths long)
- Target and 2nd horn move wrt 1st horn to focus variable energy π^+ / π^- for $\nu / \bar{\nu}$
- Mesons decay in the decay pipe. Remaining hadrons stop in the absorber
- Muons stopped by ~240m of rock



Determining Neutrino Flux



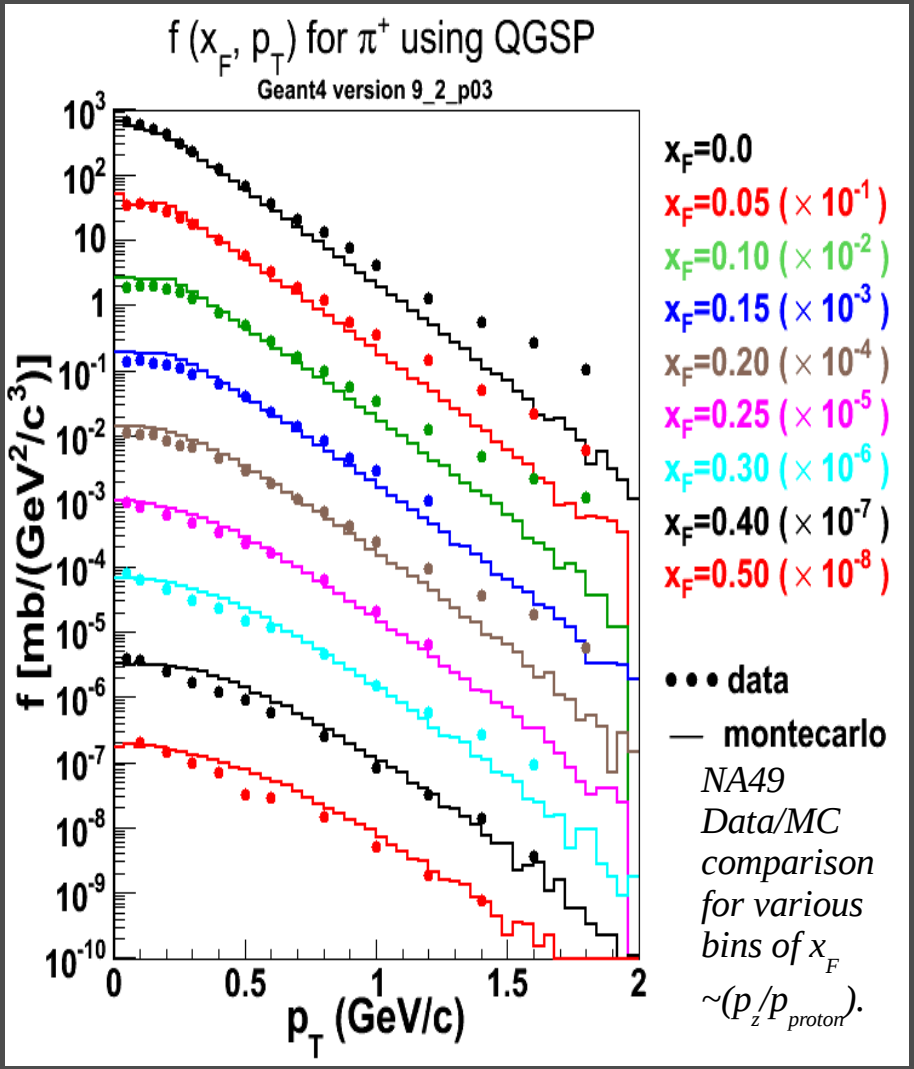
Neutrino Flux prediction for 3 unmodified hadron production models.

MINERvA takes a three prong approach to flux measurement:

- Measurements from external hadron production experiments
- Special runs to tune MC using external muon monitors in beam
- Independent MC based on MINERvA data. Done *in situ.*

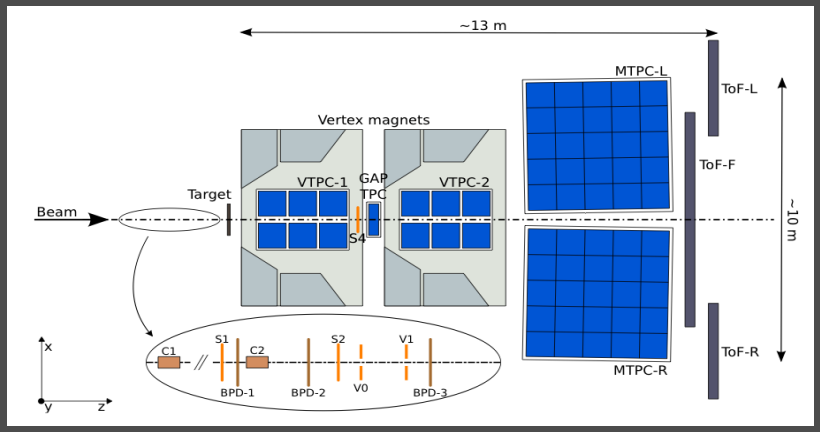
- Flux determination very important for all MINERvA analyses
- Most physics goals of DIS are dependent on flux measurements. Ratios not as much
- Difficult for neutrino beams. Cannot measure incoming lepton E
- Largest uncertainty in hadron production in target
- Neutrinos generated from secondary and tertiary interactions
- Difficulty modeling horn current distributions

External Hadron Production

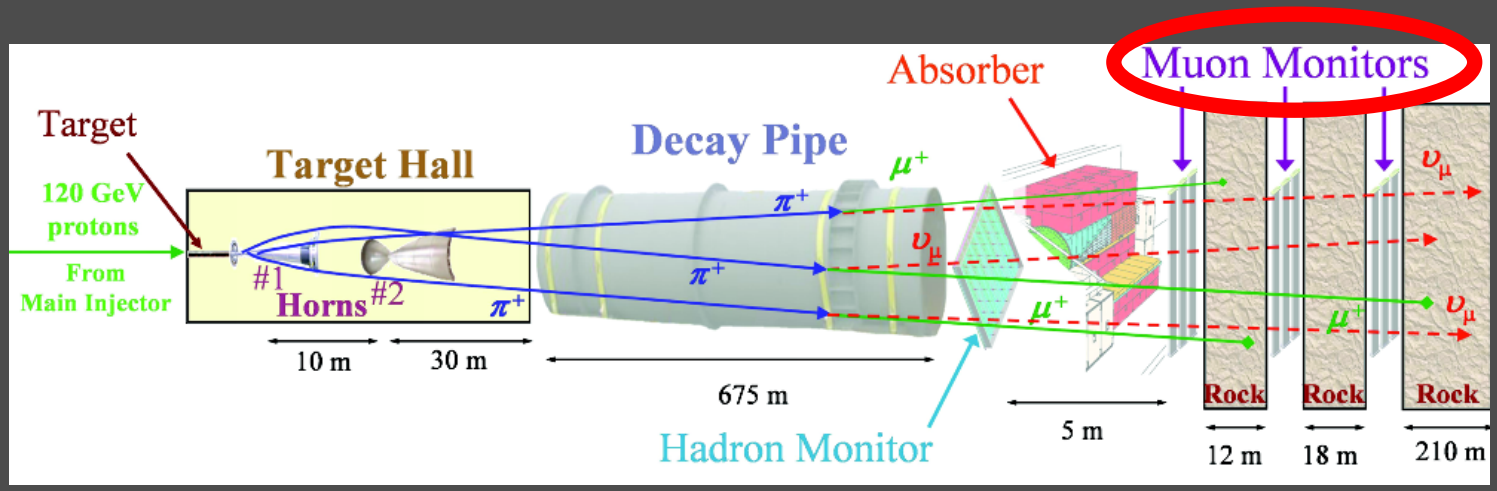


Data from: Eur. Phys. J. C 49, 897-917 (2007)

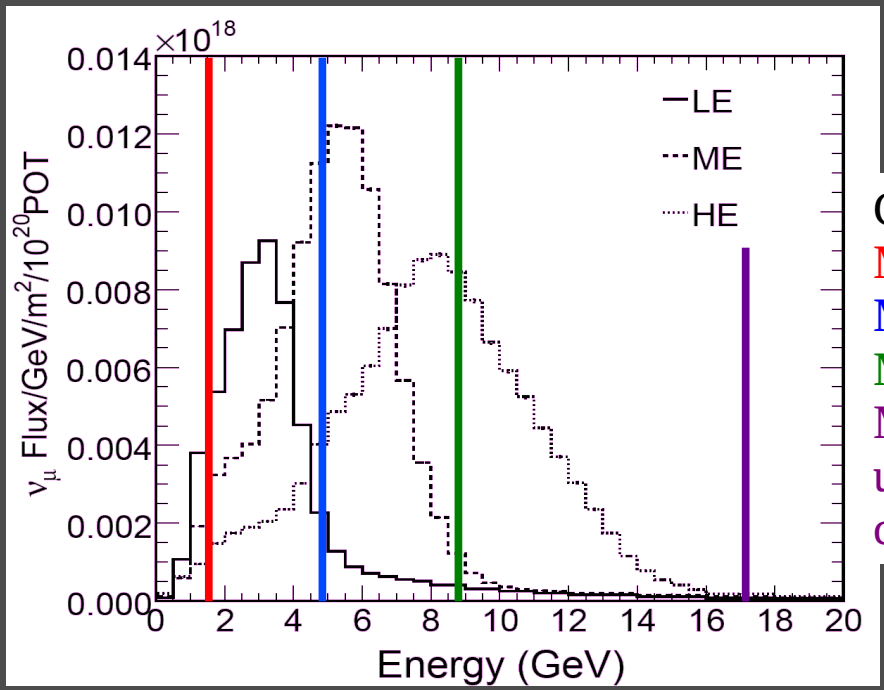
- Hadron production data invaluable to neutrino experiments
- Re-weigh MINERvA MC using NA49 data
- Similar beam energy and target material as NuMI
- Exploring dedicated hadron production run with the SHINE collaboration at CERN (below)



Muon Monitor Analysis



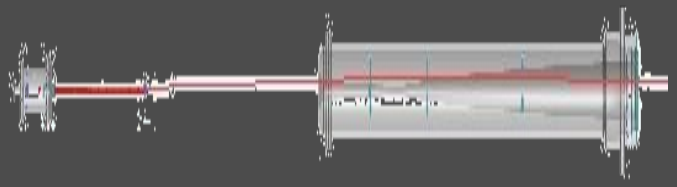
4th Monitor



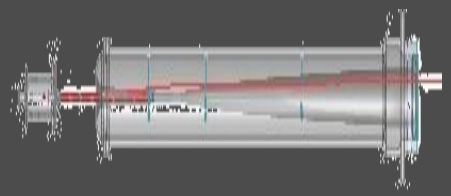
Cutoff E:
Monitor 1
Monitor 2
Monitor 3
Monitor 4: under construction

- Leverage special runs to fit $\Phi(p_T, x_F)$ of parent mesons
- Analyze *muons* using monitors in beam
- Add 4th monitor this summer for increased coverage / sensitivity for ME and HE run

Special Run Beam Configurations

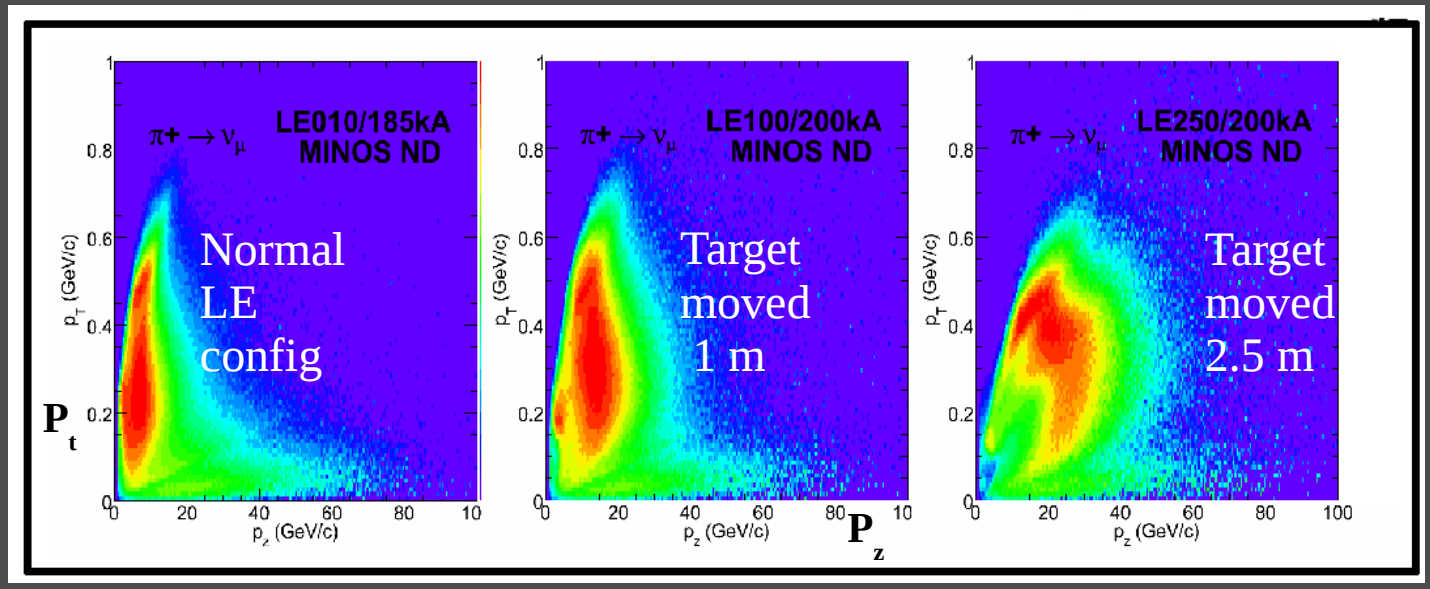


"High Energy" Configuration



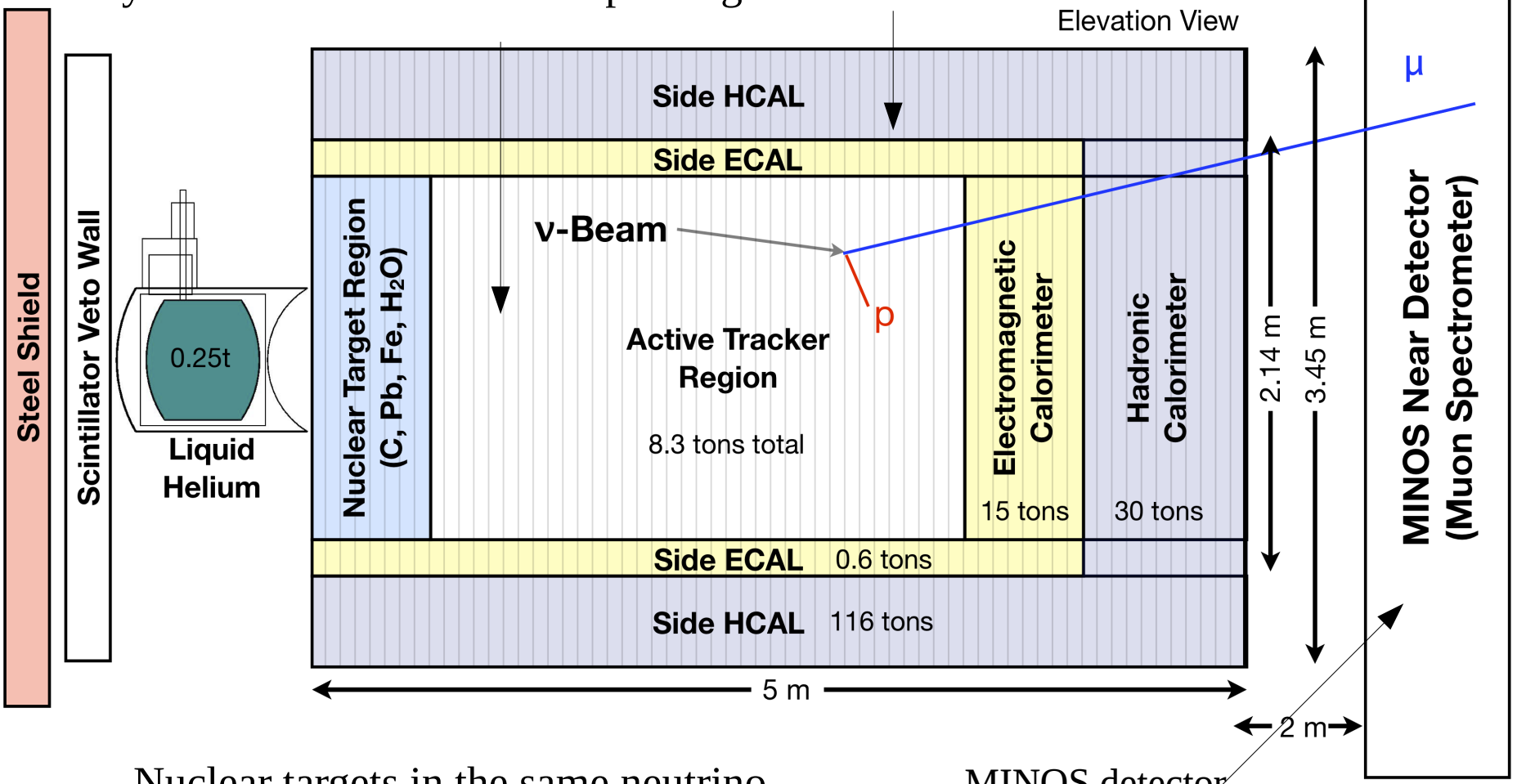
"Low Energy" Configuration

- The Graphite NuMI target is mounted on rails allowing us to alter neutrino energy spectrum
- Target pulled out: only focus very low angle, high energy pions = higher neutrino energy
- Can also vary horn current to change p_T
- Use different target configurations and horn currents to tune flux MC using events in MINERvA



Enter MINERvA

Planes of scintillator strips, surrounded
by steel outer frames make up hexagonal modules

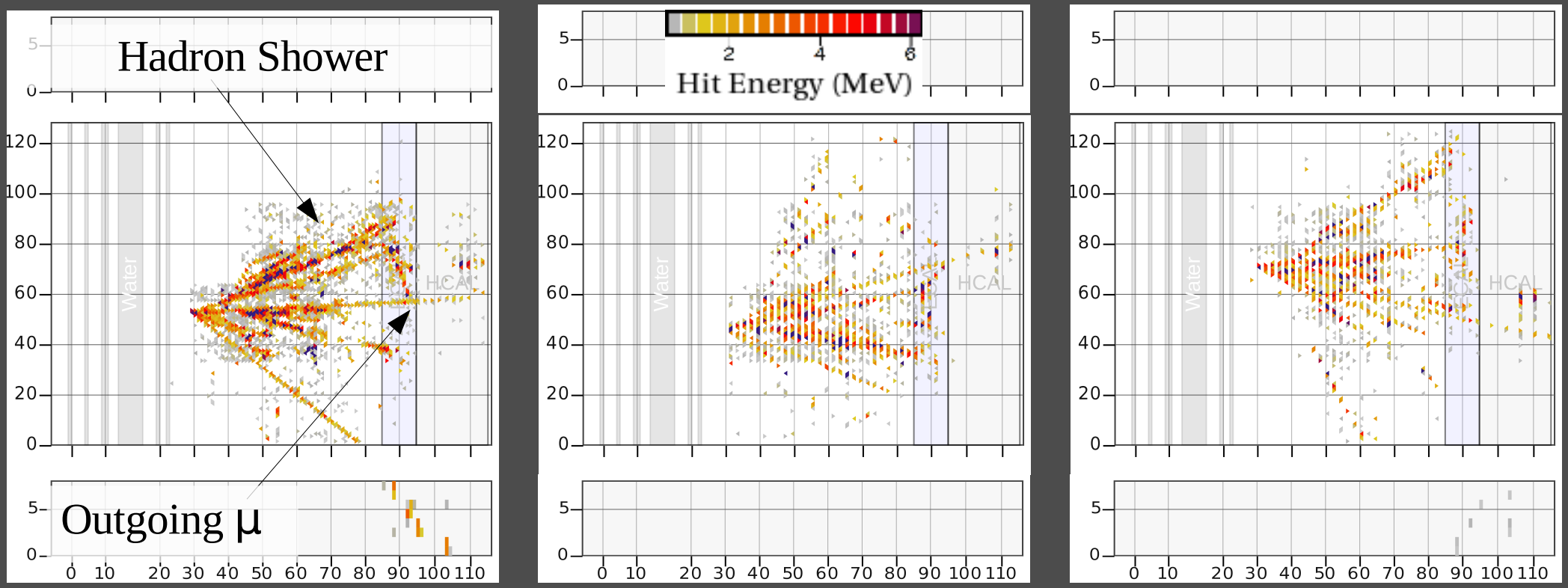


Nuclear targets in the same neutrino beam allow MINERvA to make A-dependent physics measurements

MINOS detector used for escaping muon ID and reconstruction

Neutrino DIS in MINERvA

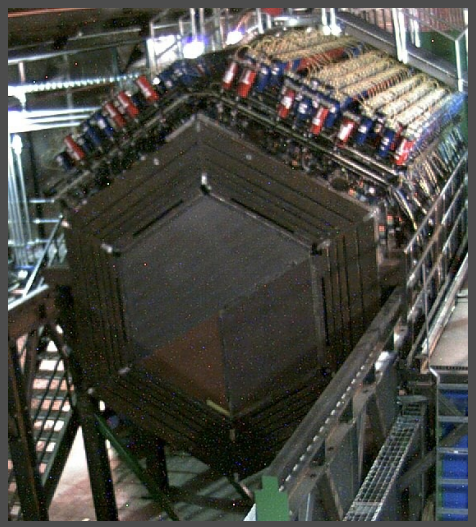
X view *U view* *V view*



- MINERvA event display showing 3 stereo views (left) + outer detector
- The challenge is to reconstruct the energy of outgoing muon + hadronic shower

Nuclear Targets

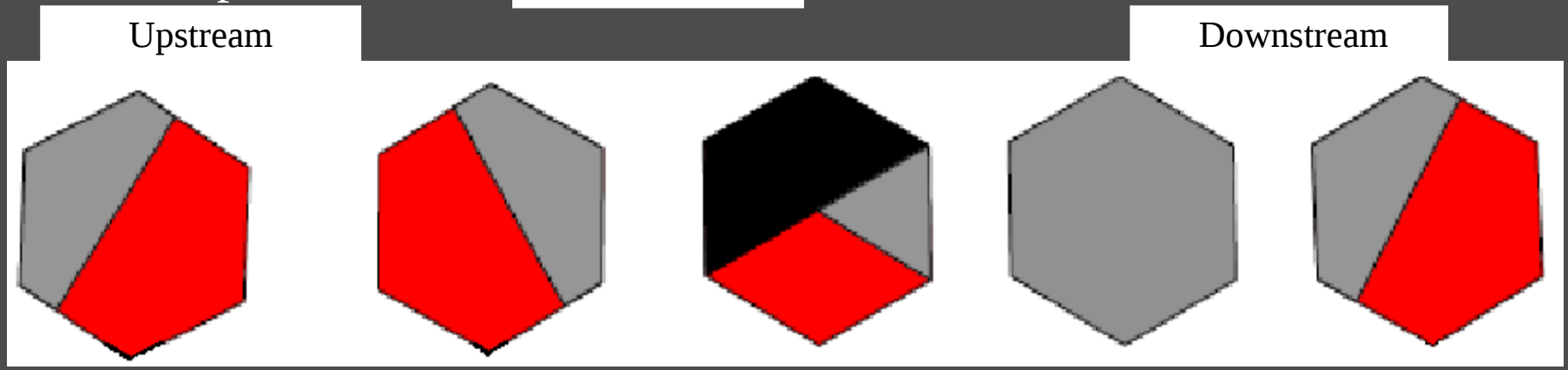
- Nuclear targets of Fe, Pb, C, He, H_2O
- Fe: Common material in calorimeters
- Pb: Stable, high A Used in calorimetry
- C: Common material in scintillators
- He: Proposal to add D
- H_2O: Common target in neutrino experiments



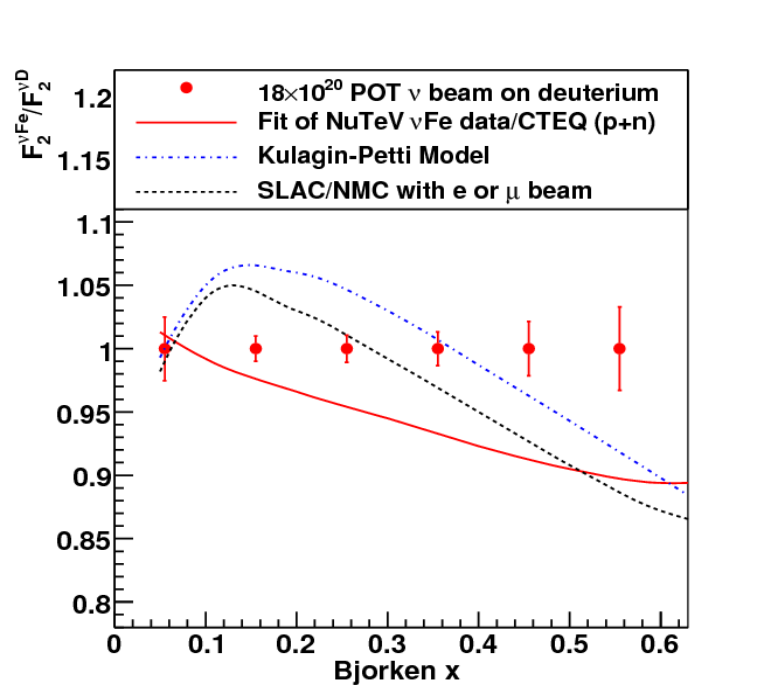
Target	Fiducial Mass	DIS Events
Scintillator	5.00 T	75.1K
Fe	0.98 T	14.8K
Pb	1.01 T	16.1K
C	0.17 T	2550

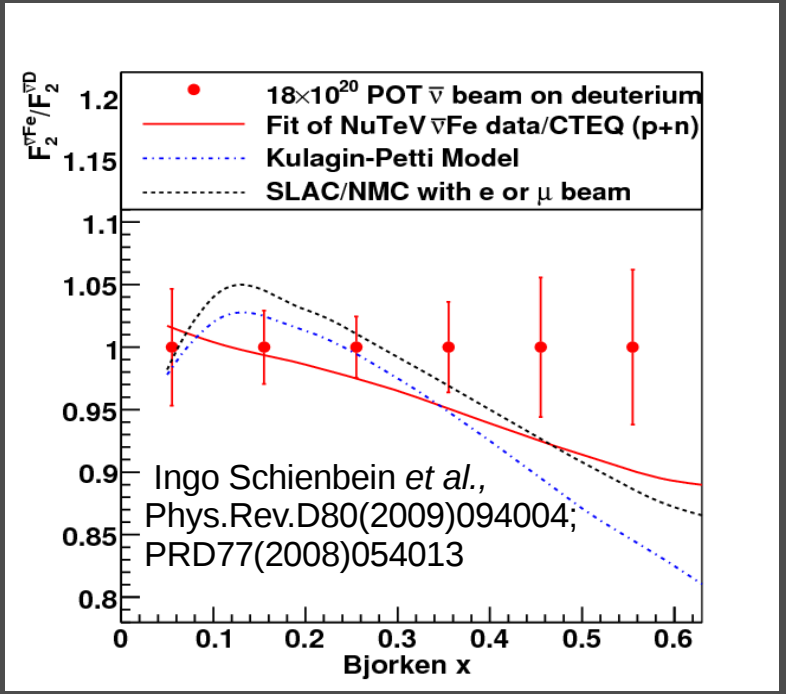
Key
Gray = Pb
Red = Fe
Black = C

$1x10^{20}$ POT, ¼ of our approved LE run



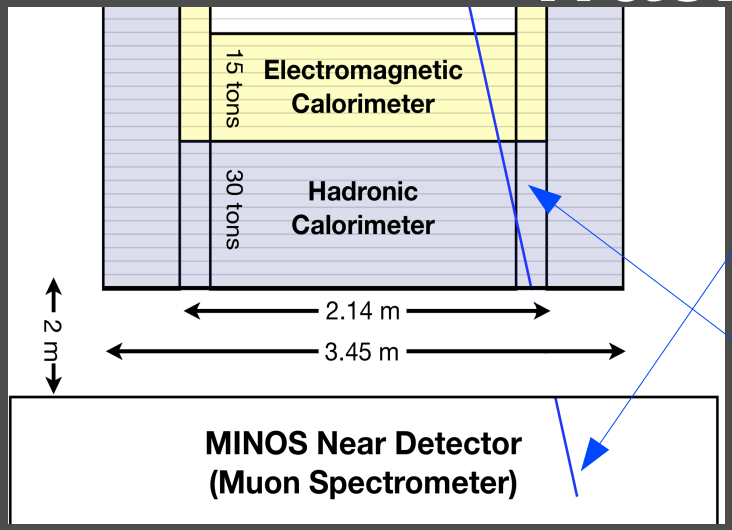
Deuterium: Projected A/D DIS Ratio





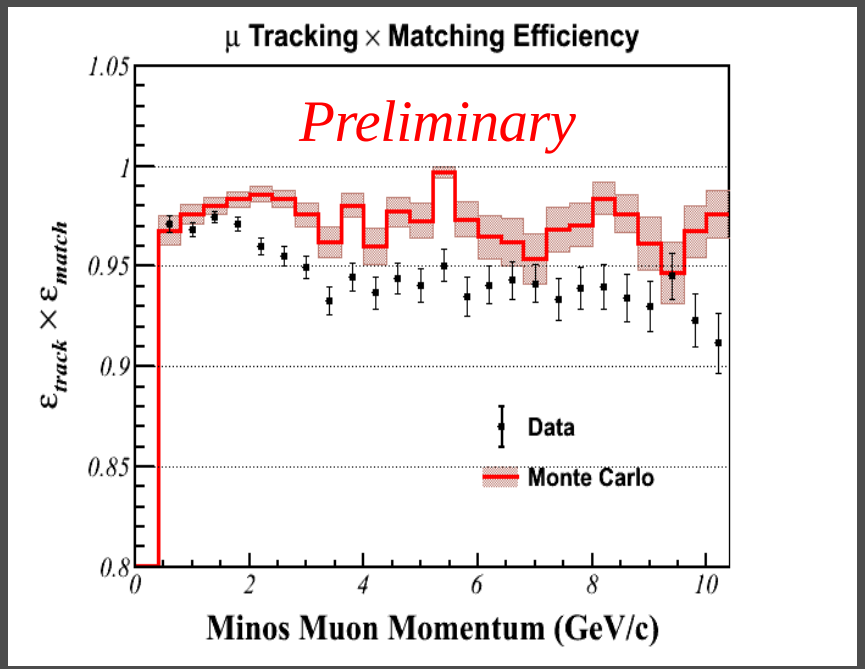
- Statistical uncertainties of Fe, C and Pb/D ratios mostly come from deuterium
- Many systematic uncertainties due to flux cancel in the ratios
- FNAL PAC recommended engineering studies to resolve safety issues with deuterium running

Details of the Detector: Muon Tracking Efficiency



Given a track here...

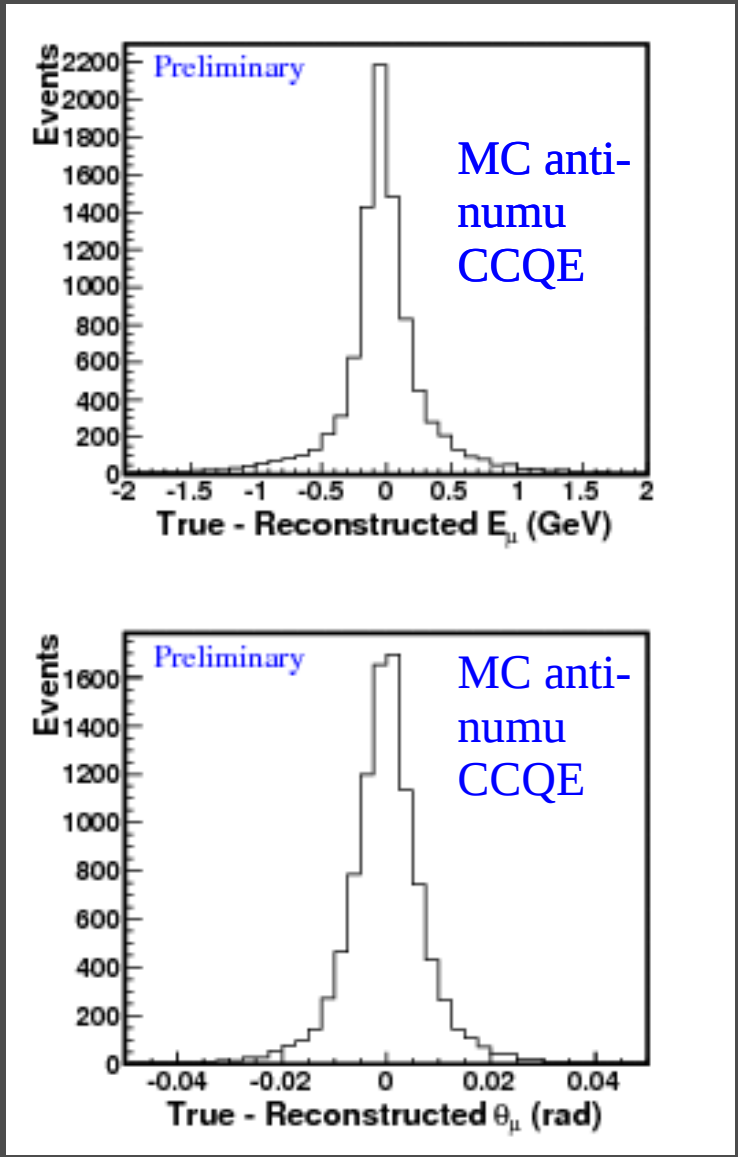
Can we find it here?



- Tracking efficiency very important metric for multiple analysis
- Match MINOS reconstructed tracks to those found in MINERvA
- Matching efficiency ~93% across all muon momenta
- Subtraction of detector dead-time from electronics improves data / MC agreement

Muon Reconstruction Performance

- MINERvA currently measures final state muon energy using MINOS
- Final state info + tracking information in MINERvA used to compute initial energy and production angle
- On right: resolution of E and theta reconstruction from MC
- Measured from CCQE cuts applied to anti-numu MC



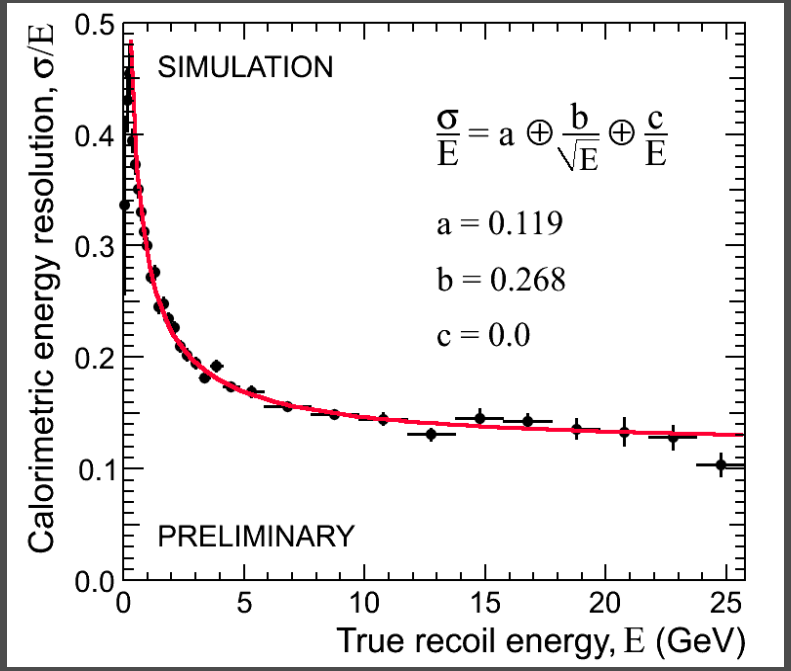
See K. McFarland, NUINT '11.

Recoil Energy Measurement

- Inclusive study classifies non-muon energy in the detector as recoil
- Account for passive material and hadron absorption in the via calorimetry
- Hadron calorimetry actively studied field by the collaboration

- MC only study
- Dedicated test beam experiment conducted to study detector response to hadrons

First pass at hadron calorimetry. Initial estimates of our energy resolution.



MINERvA Test Beam Experiment: Detector

Test Beam Goals:

•Assist in reconstruction of hadrons (crucial for DIS)

•Provide data for tuning hadron cascade models (Bertini, QGSP, etc.)

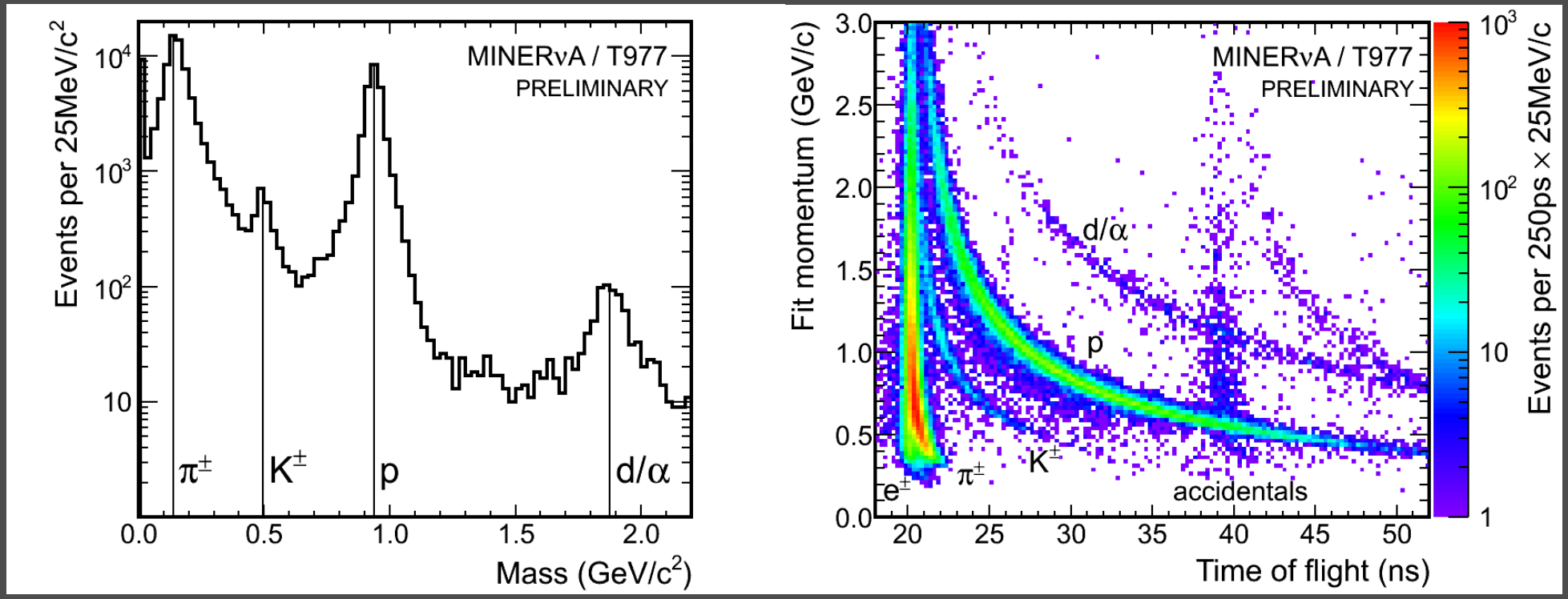
•Cross-check main detector calibrations and performance

Detector Design:

40 planes of Scintillator, plus 20 planes Fe, and 20 planes Pb.

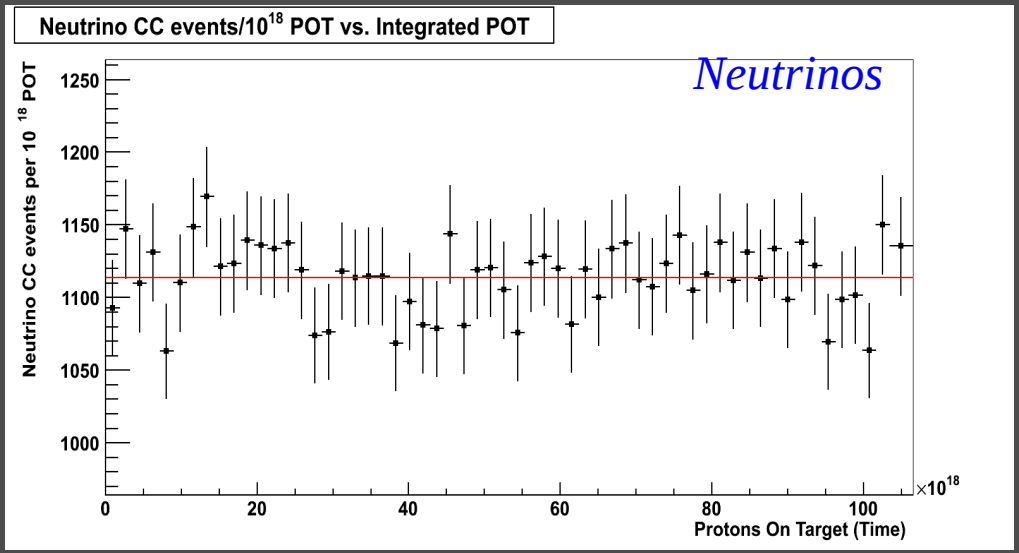
Planes configurable to mimic any part of the main detector

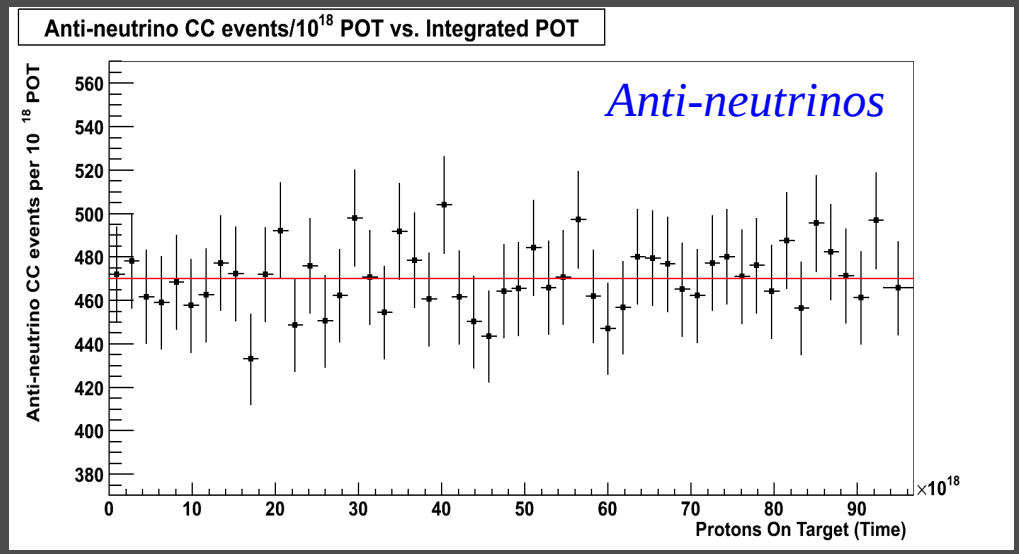
Test Beam Deliverables



- Detector response to hadrons vital for neutrino DIS
- Test beam is sensitive to the particles we expect to see in our hadron showers
- Particle identification done by time of flight measurement
- Momentum measured by wire chambers and magnets

Inclusive CC Analysis



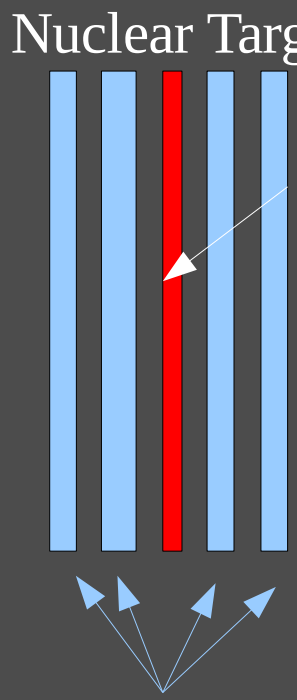


- Number of charged current events per POT delivered

- Event selection:
  - Muon track originating in the MINERvA tracker volume.
  - Muon is energy and momentum reconstructed in MINOS

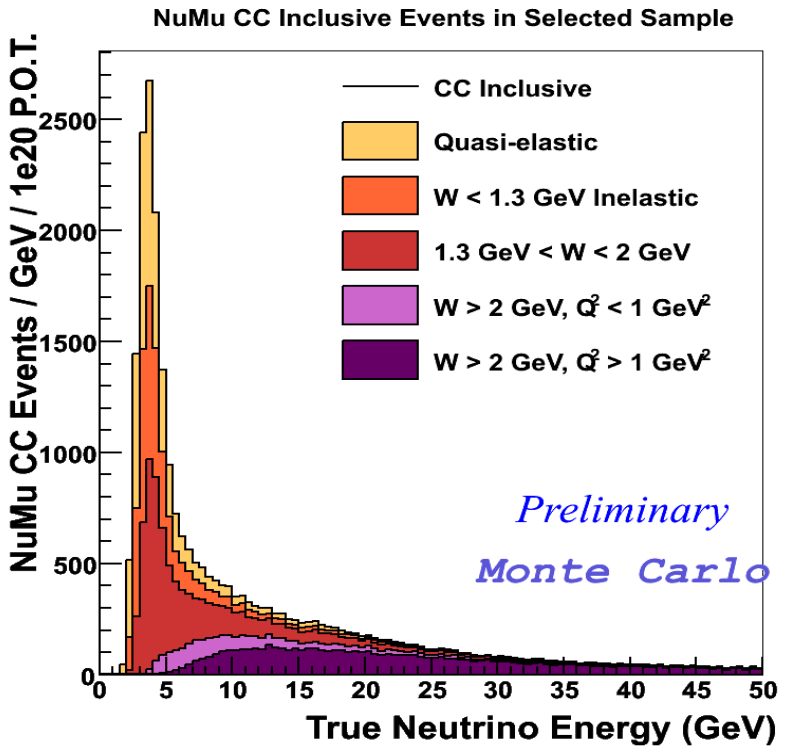
- High statistics anti-neutrino sample. Vital for F_i extraction

From CC Inclusive to CC DIS



Restrict z-vertex of events to this nuclear target. Created "enriched" samples with plastic event background

Simulation of this process →



- Right: MC of enriched nuclear target and tracker events as a function of true E_ν
- DIS event kinematics: $Q^2 > 1$ GeV^2 and $W > 2$ GeV
- ME neutrino running next year. Many more DIS events due to higher beam E (see above)

Conclusions

- MINERvA is recording DIS events as we speak. Low energy run will be completed soon
- Multiple nuclear targets in an identical neutrino beam and high-resolution detector will add significantly to our knowledge of neutrino deep inelastic scattering
- Inclusive analysis provides a springboard for a more specific DIS analysis
- Multiple methods to measure flux will aid accurate, robust cross-sections
- *Stay tuned for results soon!*

The MINERvA Collaboration

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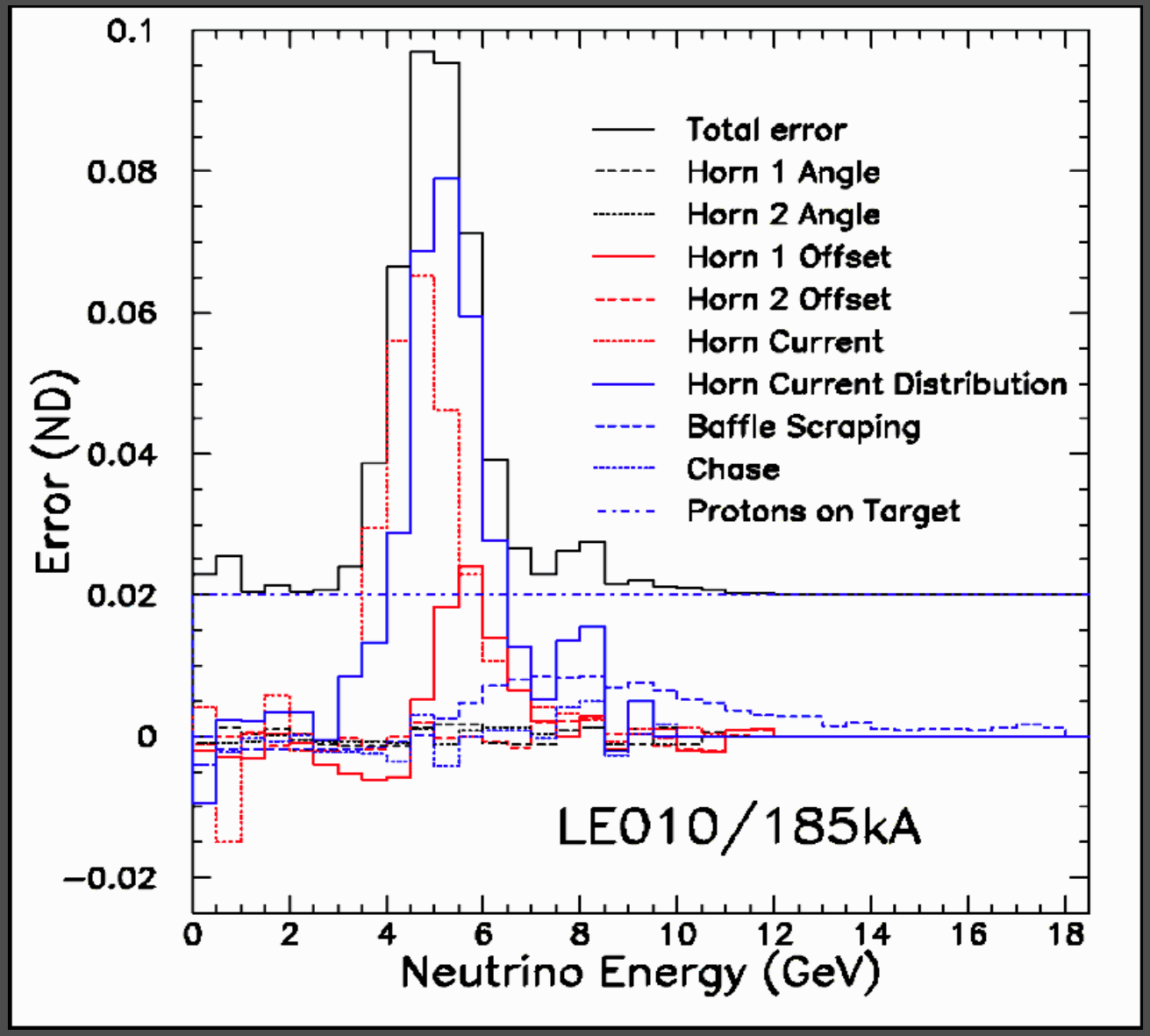
Thank you for listening!

Back up Slides

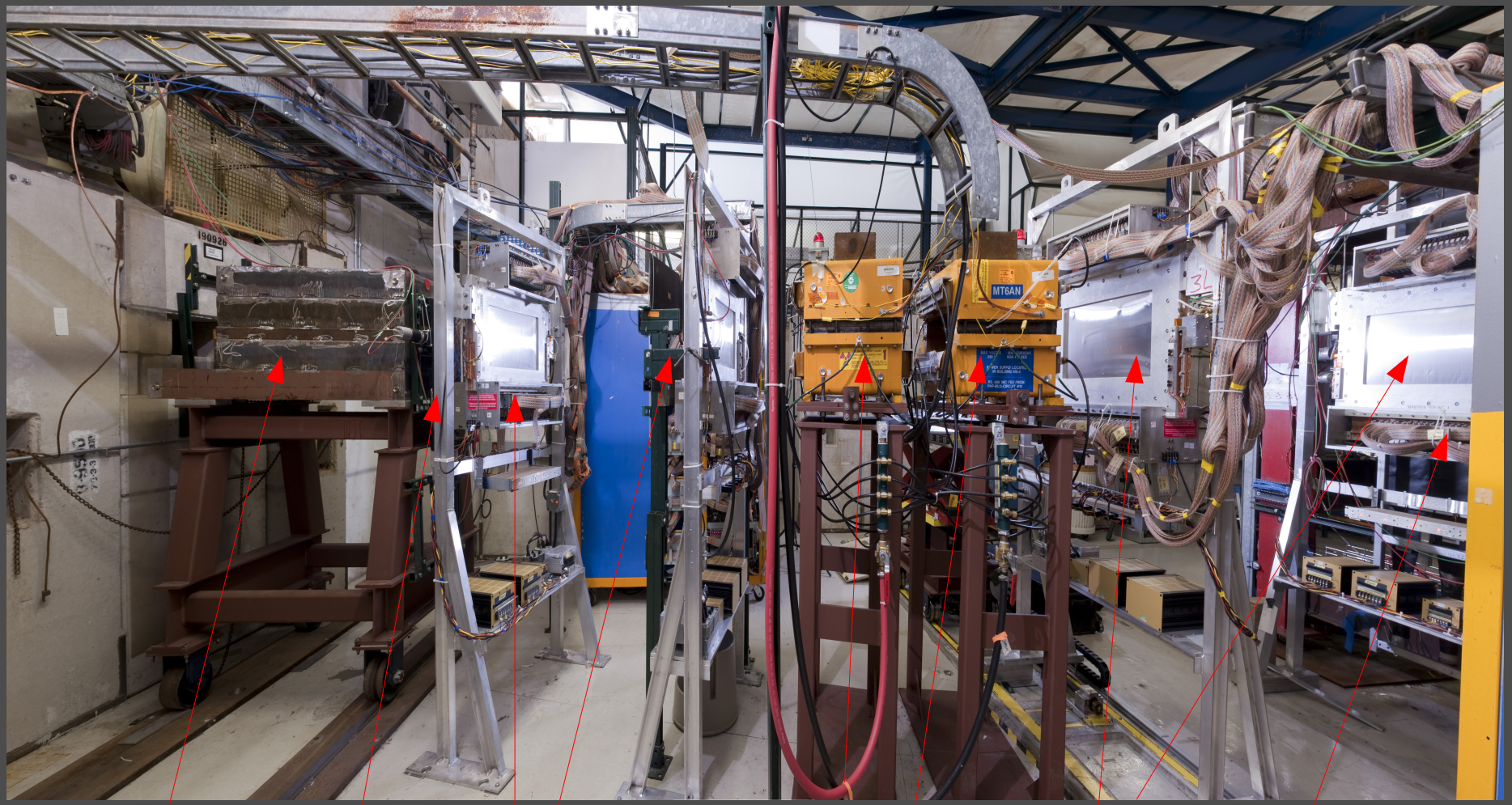
Flux Uncertainties Breakdown



Plot does NOT include hadron production errors

Z. Pavlovic, "A Measurement of Muon Neutrino Disappearance in the NuMI Beam," PhD Thesis, UT Austin 2008

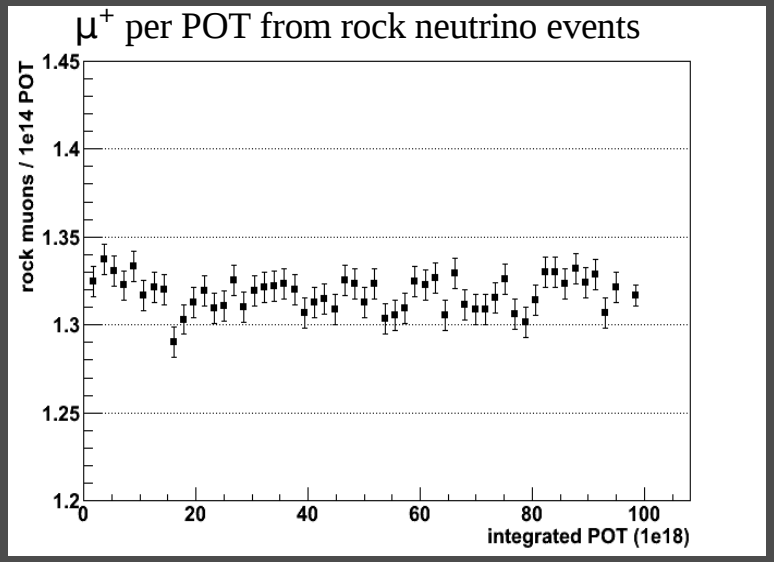
MINERvA Test Beam Experiment: Beamline

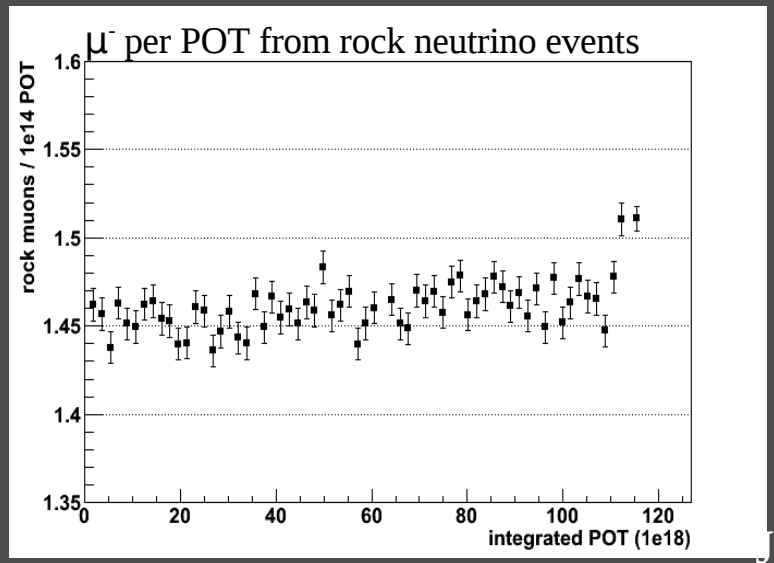


Beamline is MINERvA designed

Took data Summer of 2010 at Fermilab TBF

Main Detector and Reconstruction Stability:

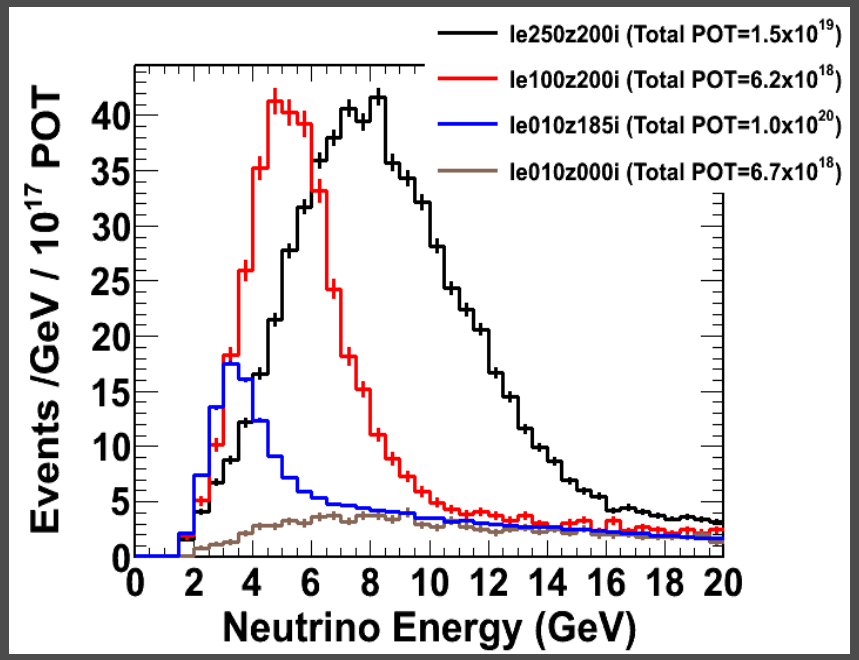


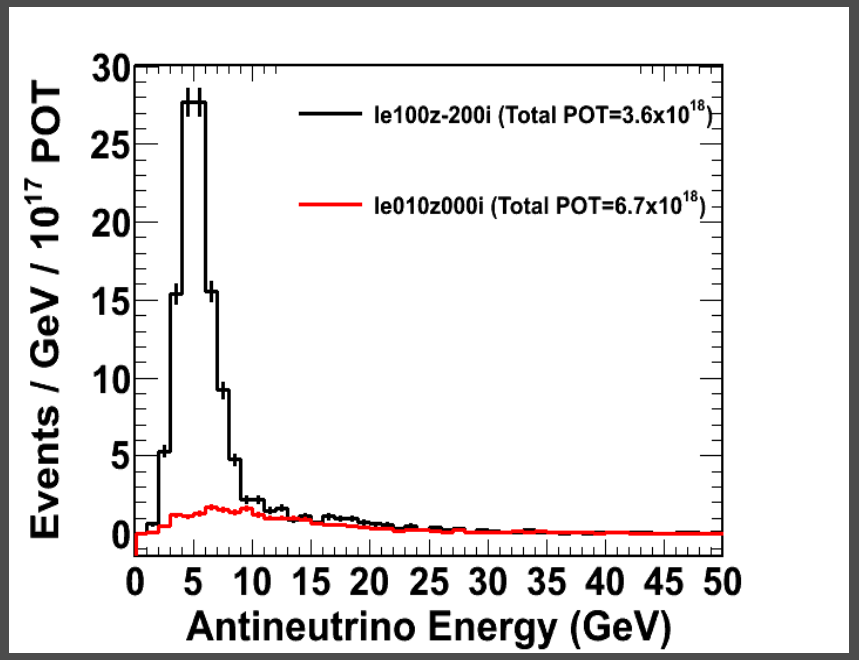


- Rock muons: muons from neutrino interactions with the surrounding rock
- Valuable calibration and validation source
- Particles tracked through MINERvA and matched into MINOS
- Demonstrate the stability of the MINERvA/MINOS as well as integrity of the NuMI target

Special Run Analysis

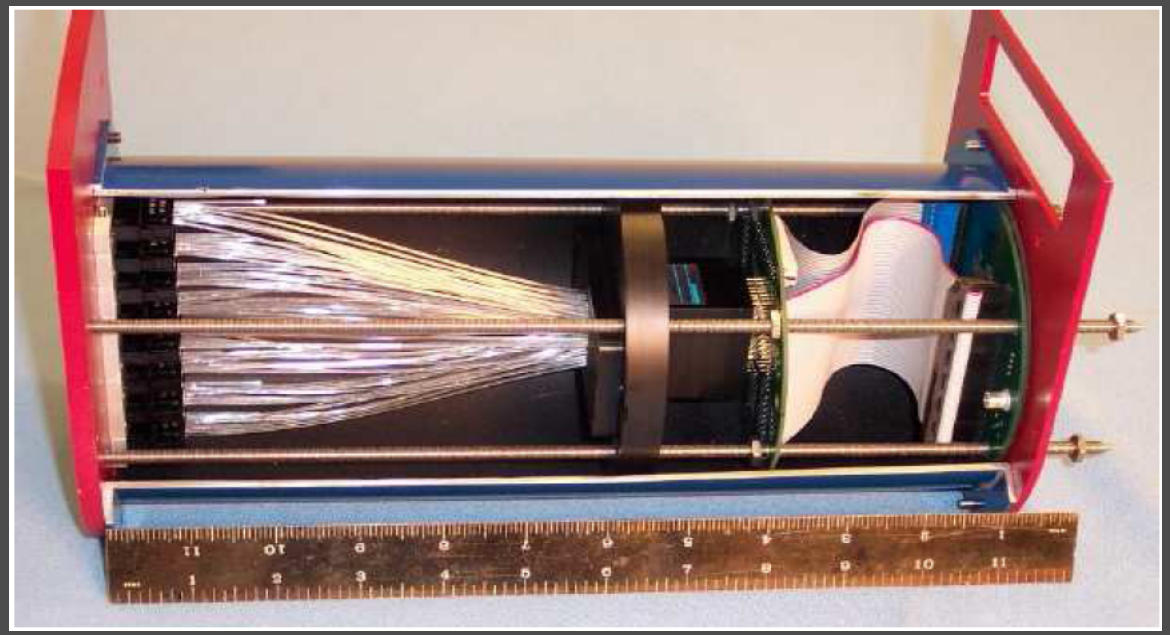
- Simultaneously fit $\Phi(p_T, x_F)$ for different beam configurations and de-couple various systematic factors
- Analyze CC event sample (below)





MINERvA Readout and PMTs

WLS fiber -> Clear optic fibers -> MINERvA PMT boxes (bottom)
Fibers terminate on a plastic “cookie” which mechanically mates to Hamatsu M-64 PMT
Fiber weave separates adjacent detector channels to non-neighboring PMT pixels to reduce optical cross talk
Custom made front end board with D0 Trip-ts digitizes signal

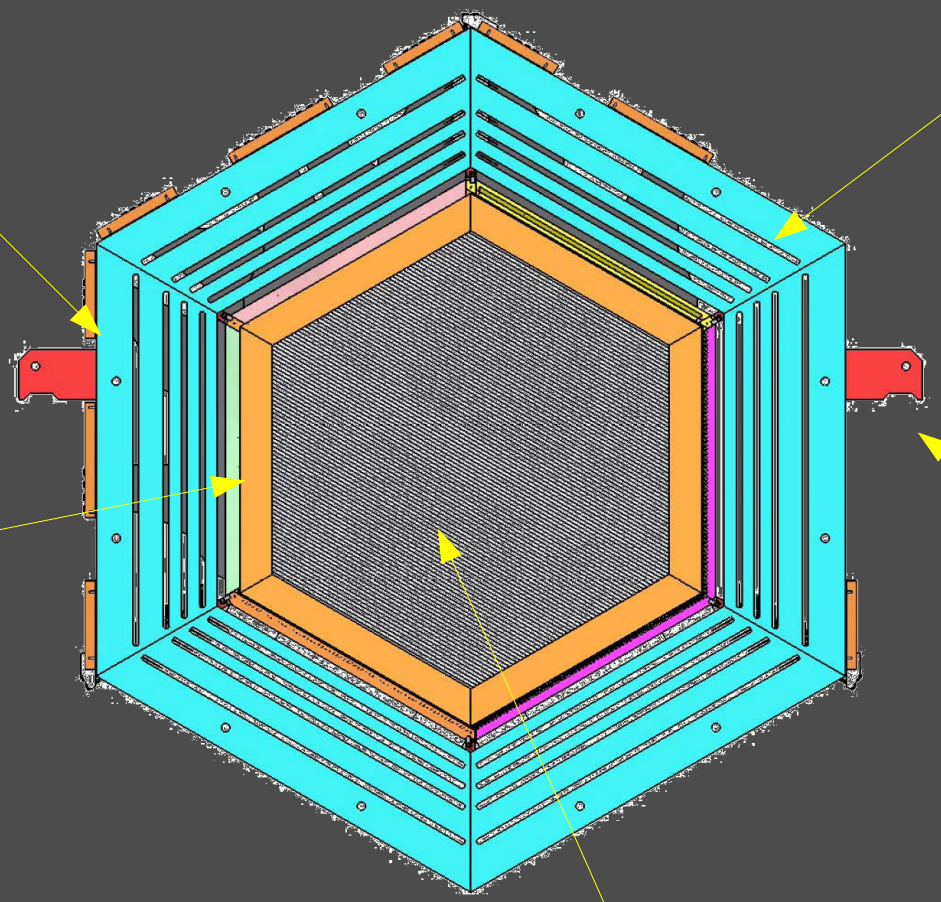


Cut away of a PMT box, showing the weave, cookie and PMT. MINERvA has 507 PMT boxes installed.

A MINERvA Module

Outer Detector Frame

Scintillator Bars



Lead collar

Steel supports used to hang modules on rail.

Inner Detector:
Plastic scintillator strips